

## Recent Results from CARMA

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### Abstract.

The Combined Array for Research in Millimeter-wave Astronomy (CARMA) is a heterogeneous array of 23 telescopes designed to operate in the 1 cm, 3 mm, and 1 mm atmospheric windows. The array is a merger of the eight 3.5 m antennas from the Sunyaev-Zel'dovich Array, the nine 6.1 m antennas from the Berkeley-Illinois-Maryland array, and the six 10.4 m antennas from the Owens Valley Radio Observatory (OVRO). As a signature of Tom Phillips' legacy, three of the CARMA antennas are from the original 3-element OVRO interferometer built under Tom's leadership in the early 1980's. Recent CARMA results are presented on the structure of circumstellar disks and the molecular gas distribution in M51.

## 1 Introduction

CARMA, the Combined Array for Research in Millimeter-wave Astronomy, is designed to study the origins of planets, stars, and galaxies, and to measure distortions in the cosmic microwave background due to clusters of galaxies that formed soon after the Big Bang. CARMA is a hybrid instrument consisting of eight 3.5 m telescopes from the University of Chicago's Sunyaev-Zel'dovich Array (SZA), nine 6.1 m telescopes from the Berkeley-Illinois-Maryland Association (BIMA) array, and six 10.4 m telescopes of the California Institute of Technology (Caltech)/Owens Valley Radio Observatory (OVRO) array. All 23 antennas are now located at Cedar Flat in the Inyo Mountains of eastern California. CARMA's history can be traced in part to Tom Phillips. His dedication and efforts as OVRO director in the early 1980's led to the construction of the initial three-element OVRO interferometer; all three antennas are now part of CARMA.

CARMA is a remarkably versatile interferometer that operates in the 1 cm, 3 mm, and 1 mm atmospheric windows. For millimeter-wavelength observations, the 6.1 m and 10.4 m antennas can be arranged in 5 different configurations to provide baselines from 8 m to 1.9 km. In the future, the 3.5 m antennas will be full integrated into the array to provide high resolution observations of the SZ effect in galaxy clusters, and to ultimately provide synthesis imaging with 23 antennas. Recent results on the structure of circumstellar disks and the molecular gas content of M51 are described below.

## 2 Circumstellar Disks around Young Stars

Most young, solar-type stars are surrounded by optically-thick circumstellar disks. These disks serve as conduits for the accretion of material onto the star and are the likely sites of planet formation. Figure 1 presents CARMA images of the dust continuum emission at a wavelength of 1.3 mm from the circumstellar disks surrounding the young stars RY Tau and LkCa 15. Both disks have been clearly resolved by CARMA to reveal spatial structure on size scales as small as 20–50 AU. These images provide important constraints on the initial conditions for planet formation.

The disks shown in Figure 1 illustrate the diversity of circumstellar structures observable with CARMA. In RY Tau, the dust emission is centrally peaked and is consistent with a rising dust surface density distribution with decreasing radius (Isella, Carpenter, & Sargent 2009). On the other hand, LkCa 15 is an example of a “transition” disk where the inner disk is depleted of small dust grains (e.g. Espaillat *et al.* 2008). The lack of inner disk material is often interpreted as a signature of grain growth, or the presence of a stellar or planetary companion that has dynamically cleared the dust. The CARMA image of LkCa 15 clearly shows a reduction in the amount of millimeter emission within the inner  $\sim 25$  AU of the disk (see also Piétu *et al.* 2006).

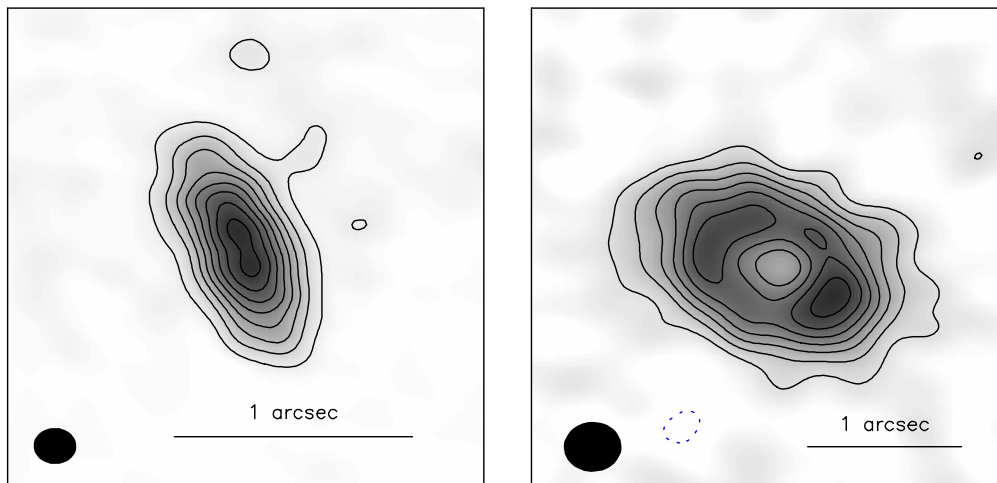


Figure 1. CARMA images of the  $\lambda 1.3$  mm continuum emission from the circumstellar disks around the young stars RY Tau (left) and LkCa 15 (right). The angular resolution of the observations, as indicated by the black ellipse in the lower left corner of each panel, is  $0.15'' \times 0.18''$  for RY Tau and  $0.33'' \times 0.38''$  for LkCa 15. The RMS noise in the image is  $\sigma = 0.8 \text{ mJy beam}^{-1}$  and  $0.7 \text{ mJy beam}^{-1}$  for RY Tau and LkCa 15, respectively. Contour levels begin at  $3\sigma$  for both sources, and are spaced by  $5\sigma$  for RY Tau and  $3\sigma$  for LkCa 15.

### 3 Molecular Gas in M51

CARMA has imaged the entire disk of the M51 galaxy in CO (J=1–0). The data were combined with a single-dish map obtained with the Nobeyama 45 m telescope to trace the molecular gas in the arm and interarm regions (Koda et al. 2009). Figure 2 shows the image constructed from the combined data sets. With its high sensitivity, CARMA has detected GMCs with masses down to  $\sim 4 \times 10^5 M_\odot$ , which corresponds to the typical GMC mass in the Milky Way. The most massive GMCs (also called giant molecular associations or GMAs; Vogel, Kulkarni, & Scoville 1988) have masses of  $M > 10^7 M_\odot$  and are found along the spiral arms in M51 but not in the interarm regions. The GMAs in M51 are therefore short-lived — they form and die across spiral arms. On the other hand, a number of GMCs with masses of  $\sim 10^{5-6} M_\odot$  exist even in the interarm regions, suggesting they are long-lived. The GMAs are not dissociated into atomic gas since the molecular gas fraction is very high ( $\sim 70\%$ ) even in the interarm regions. Instead, GMAs likely break up into smaller GMCs. The scenario of GMC evolution in M51 is thus that pre-existing GMCs coagulate and form massive GMAs on spiral arms. A detailed description of these results is presented in Koda et al. (2009).

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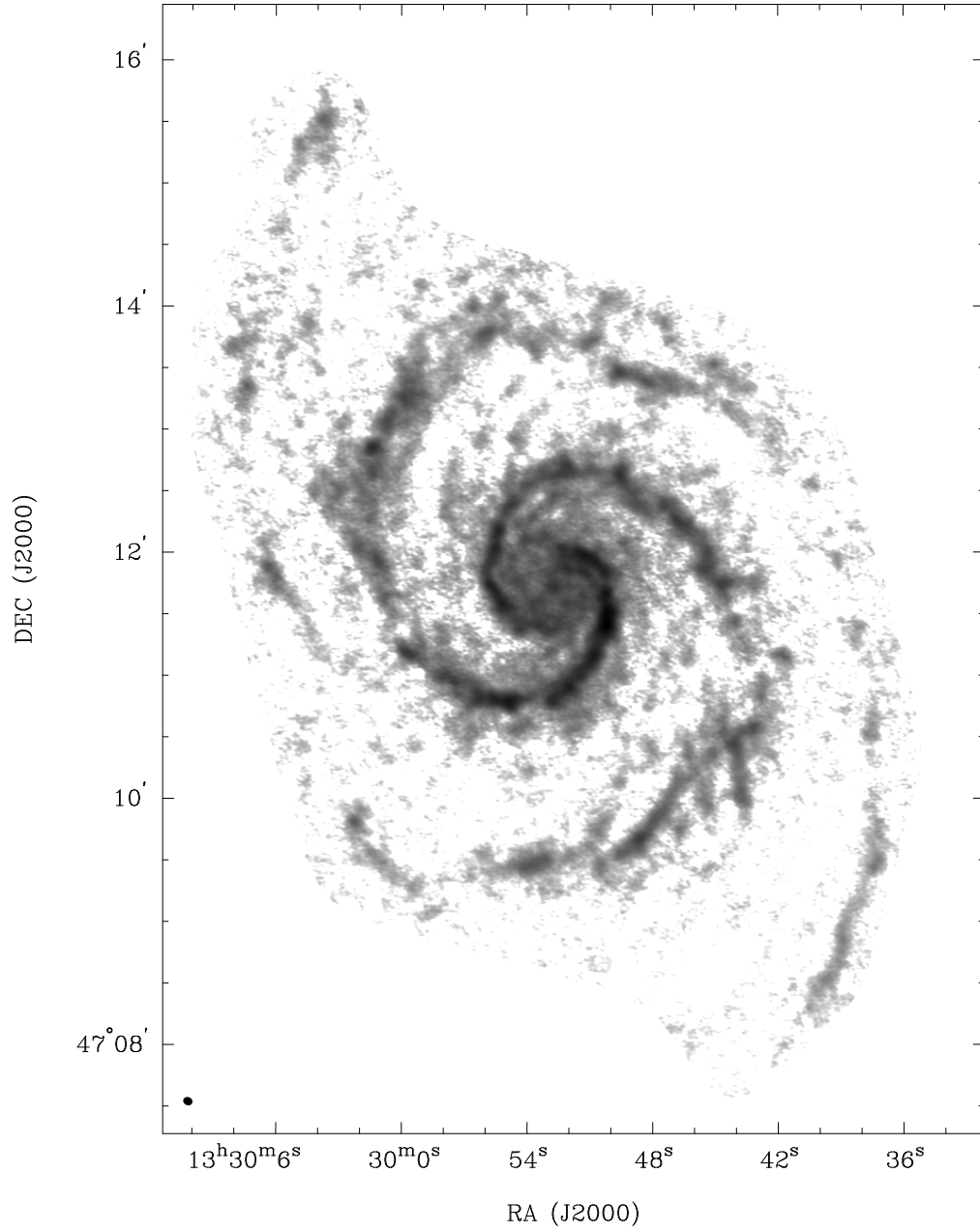


Figure 2. CO (J=1–0) mosaic of M51 obtained by combining 151 CARMA pointings with a single-dish map from the Nobeyama 45 m telescope (Koda et al. 2009). The size of the synthesized beam, indicated in the lower left corner, is  $4.1'' \times 3.3''$ .